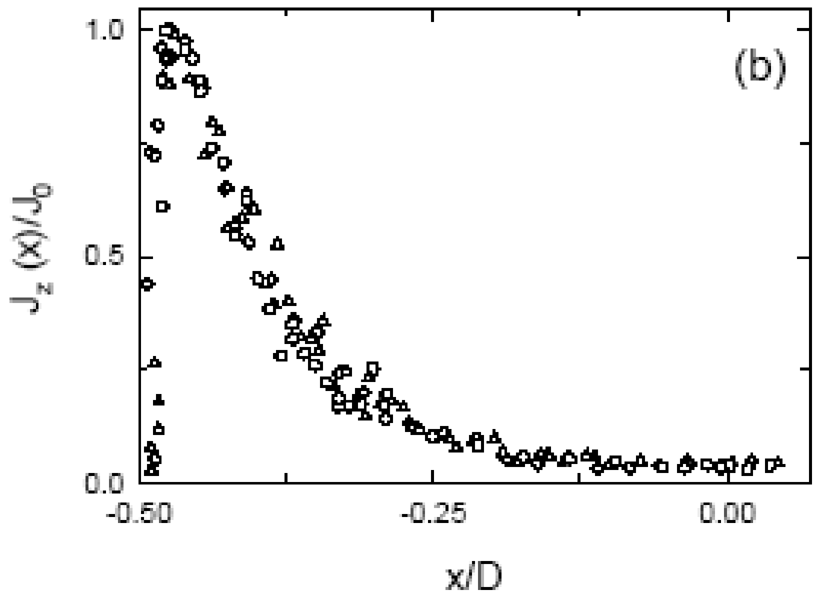
Vorticities, Coherent Structures, and Surface Roughness Effect in Turbulent Thermal Convection

Penger Tong, Oklahoma State University, DMR-0071323

Physical understanding of convective turbulence is essential for a large number of convection phenomena at geophysical scales, such as those in the atmosphere and oceans and inside the earth mantle. An important issue in the study of turbulent thermal convection is to understand how heat is transported through a turbulent fluid, a process which affects many industrial applications ranging from heat exchangers to reentry vehicles in the space flight. In controlled laboratory experiments, one studies turbulent heat transport by applying a temperature difference across a fluid layer and measuring the vertical heat flux as a function of two experimental control parameters: the Rayleigh number Ra and the Prandtl number Pr. Many global heat transport measurements have been carried out recently in various convecting fluids and under different experimental conditions.

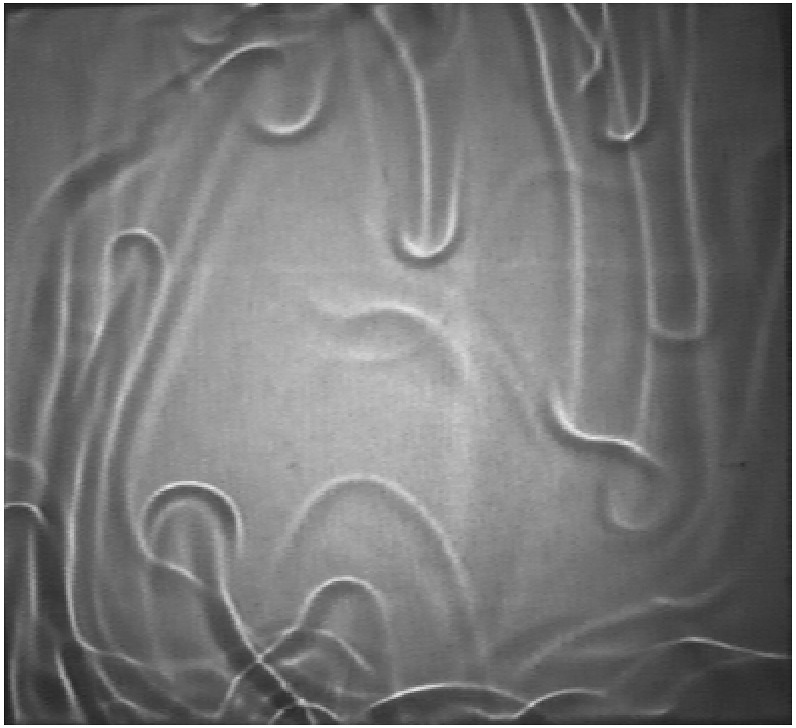


A main issue of an unresolved theoretical debate is whether the heat transport in turbulent convection is determined primarily by thermal plumes or by the large-scale circulation. To answer this question, we conducted simultaneous velocity and temperature measurements, from which we obtain the local convective heat flux $J_Z(\mathbf{r})$ in the vertical direction over varying Rayleigh numbers and spatial position **r** across the entire convection cell [Physical Review Letters. **90**, 074501 (2003)]. The figure shown above displays the measured $J_Z(x)$ at various horizontal positions along a cell diameter from the sidewall (x/D= -0.5) to the cell center (x/D=0). The measured $J_Z(x)$ is normalized by its peak value J_0, which increases with Ra. It is seen that the vertical heat flux concentrates in the sidewall region and the flux profile $J_Z(x)/J_0$ remains invariant with Ra (shown in different symbols). The vertical heat flux at the cell center is small but is definitely non-zero. It accounts approximately for 5% of the peak value J_0 near the sidewall.

Vorticities, Coherent Structures, and Surface Roughness Effect in Turbulent Thermal Convection

Penger Tong (PI), Oklahoma State University, DMR-0071323

The figure on the right shows a shadowgraph taken from a cylindrical cell filled with a viscous fluid. It is seen that the spatial distribution of the thermal plumes inside the convection cell is not uniform. The thermal plumes organize themselves in the closed cell with rising warm plumes accumulated on the left side and falling cold plumes are on the right. From these measurements we conclude that the dynamics in turbulent convection is determined primarily by the thermal plumes. The spatial separation of warm and cold plumes and the resulting large-scale circulation provide a fast channel along the cell periphery for the transport of heat. Because velocity fluctuations in the central region are strong, most thermal plumes are mixed up in the region. Nevertheless, there are still some unmixed warm and cold plumes remained (as seen in the figure), which give rise to a non-zero J_z in the region. The experiment, therefore, settles a long-debating issue on how heat is transported in small aspect-ratio cells.



Education: The current grant has been supporting 1 undergrad, 1 grad student, 1 postdoctoral fellow and 1 summer REU student. They have been fully involved in a wide range of research activities in a program at the boundaries between physics, fluid mechanics, and chemical engineering. The students and postdoctoral fellow involved have received broad training in laser velocimetry, thermometry, and optics, which will prepare them for a range of careers in academe, industry, and government.